3.2 RESULTS FOR RCS STATIC

Signature representation of the target is critical to portions of simulated engagements with radar-directed gun systems. As long as the aircraft and radar are widely separated, the target signature can be portrayed in a far-field sense. In this representation, the signature at a certain viewing aspect is assumed constant and independent of range. The far-field region starts at a distance of $2d^2/\lambda$ where d is the dimension of the target object and λ is the wavelength of the tracking radar. At separations equal to or greater than this range, the target object appears essentially as a point and can be treated as a single reflector rather than a collection of reflectors.

As the separation distance decreases, the target moves into the sensor's near-field region. In the near-field, the interference and reinforcement phenomena caused by the various target reflectors will be dynamic, and the signature viewed from a certain aspect will change as a function of range. One problem encountered in trying to model the near-field case is that data to support calibration are scarce. Thus, even though simulations include a thorough representation of signal processing circuitry, it is often necessary to use far-field data when the near-field should be employed.

RCS of the target determines how much energy is returned due to target position and orientation for the frequency and polarization of the radar. The RCS for a target can be user-defined via constant values and variations (sinusoidal or random), but for most targets it is obtained from tables. There are three angles which determine the attitude and heading of the target: roll, yaw, and pitch. A radar can illuminate every point on the target by rotating it through the full range of the three angles. There are three combinations of three angles taken two at a time, and thus three formats for the RCS data tables that may be inputs for the model. In all three of the formats, there are angular limits on the table values, but the target angles have no limits and can go from 0 to 360 degrees. Using the RCS table provided for a given target, the program selects the closest available data based upon frequency and polarization of the threat radar. Within this data set the RCS value for a particular target aspect is computed by interpolating between the closest data pairs in azimuth and elevation. The various formats for RCS tables accepted by *RADGUNS* are described and depicted in Volume 1 of the documentation.

Table 3.2-1 summarizes results of findings for this FE based upon comparisons between inputs to the program and internal values computed by the program during execution. The data used was reduced from measured returns produced by a helicopter in flight while tracked by a high frequency radar.

TABLE 3.2-1. Summary of Findings for Static RCS FE.

Data Source	Major Conditions	Statistical MOEs	Results
Army Helo Test	Hovering helicopter No clutter	Central tendencies	Close agreement
	No multipath	ANOVA	< 5% total variation between groups
		F test	95% confidence interval
		Correlation coefficient	> 0.7
		Covariance factor	> +1.0

3.2.1 Assessment – Case 1

Assessment Description

Test Data Description. Range tests conducted by the Army to validate a helicopter detection model measured signal returns from an attack helicopter at the radar PRF rate. The test aircraft performed a 360-degree hovering pedal turn while being illuminated with a high (X-band) RF source. In-phase and quadrature data were recorded and post-processed to obtain RCS values in dBsm at 1-degree increments in azimuth about the zero-degree roll angle plane. Figure 3.2-1 is a polar plot of the source data resulting from this process. The asymmetrical signature pattern is probably due to variations in aircraft pedal turn rate, fluctuations in pitch/roll angles, and/or fuselage/stores irregularities on the test aircraft.

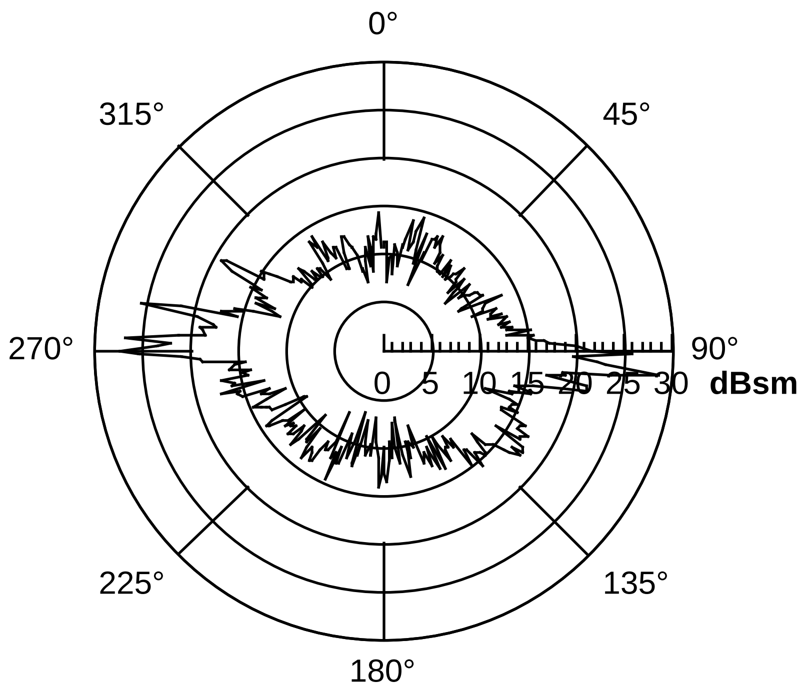
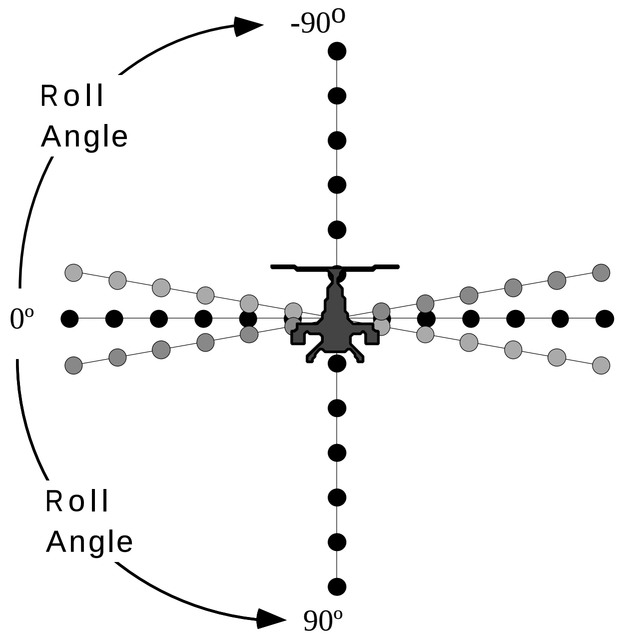
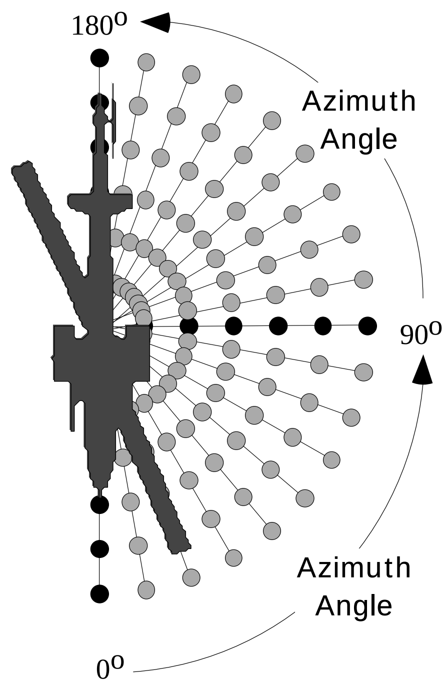


FIGURE 3.2-1. RCS Data from Range Test.

Even though the model is capable of handling RCS data at the 1-deg resolution level, most of the signatures provided with it have been aspect-smoothed (i.e., averaging RCS values for each 10-deg interval in azimuth and 10 deg in roll or pitch). Both 1-deg and smoothed 10-deg resolution data were used for different portions of this assessment. The test data were spread s shown in Figure 3.2-2. The model assumes RCS data symmetry about the Z-axis for each lateral hemisphere.



(a) Roll Angle.



(b) Azimuth Angle.

FIGURE 3.2-2. *RADGUNS* RCS Attitude Reference System.

The linear flight paths used for simulation were at a low altitude (5 m) and at sufficient ranges to ensure illumination of the zero-degree roll/pitch angles of the target. Such flight conditions would normally produce significant multipath and clutter effects; so they were disabled for all simulation runs associated with this assessment. Table 3.2-2 lists these and other simulation variables set to constant values for this assessment.

TABLE 3.2-2. Simulation Constants for RCS Tests.

Parameter	Value/Setting
Simulation type	Single scenario
Acquisition radar mode	Perfect cuing
Target S/I threshold for detection	14.0 dB
Clutter	Disabled
Multipath	Disabled
Jamming	None
Altitude	5 m
Velocity	50 m/s

Validation Methodology. *RADGUNS* should return the proper RCS value for a given target aspect and correct signal return for a given range and the same RCS value for both the acquisition and tracking radars. To investigate this general functionality, four specific objectives were developed:

a. The capability of the model to accept RCS data acquired from range testing.

b. Effects on simulation fidelity of 1-deg versus 10-deg RCS data due to symmetry, smoothing, and interpolation.

c. Consistent and accurate processing of RCS data (i.e., output matches input).

d. Correct computation of target signal for a given RCS and target range.

Statistical techniques were used to compare and contrast groups of data. The parameters examined were the arithmetic mean, median, standard deviation, percent of total variation between groups, F test, correlation coefficient, and covariance factor. These parameters were chosen because of their applicability to small sample sizes.

The MOE for central tendencies was established at a conservative ±5%. The percentage of total variation between groups (using ANOVA) was specified as less than 5%. The F test for variances (small sample) used a 0.05 significance level (95% confidence interval). MOEs for correlation and covariance were established at > 0.7 and > +1.0, respectively.

A general procedure was defined for each validation objective. These procedure sets were organized into a validation matrix (Table 3.2-3) which described the requirements being investigated, evaluation method planned, input data to be used, key output parameters, and data requirements.

TABLE 3.2-3. RCS Validation Matrix.

Validation Objective	Evaluation Method	Inputs	Outputs	Data Requirements
1. Symmetry effects	Inspection and statistical analysis	Test 1-deg RCS source data	• 1-deg RCS table • 10-deg RCS table	• Azimuth (deg) • RCS (dBsm)
2. Smoothing, and interpolation effects	*RADGUNS* runs and statistical analysis	Test 1-deg RCS source data	10-degree RCS output values	• Azimuth (deg)
3. Input-to-output comparison	*RADGUNS* runs and statistical analysis	• 1-deg RCS table • 10-deg RCS table	• 1-deg RCS output values • 10-deg RCS output values	• Azimuth (deg) • RCS (dBsm)
4. Target signal computation	*RADGUNS* runs and statistical analysis	• 1-deg RCS table • 10-deg RCS table	• 1-deg output values • 10-deg output values	• Azimuth (deg) • RCS (dBsm) • Echo (W) • Range (m)

Limitations to the scope of the validation were:

a. Only a single frequency was used.
b. Detection ranges were not measured during range testing.
c. Clutter and multipath effects were not considered.

Results

The information in this section is divided into the four validation objective subject areas. Each subject area contains separate statistical results. A summary paragraph concludes this section.

Validation Objective 1 – Symmetry Effects. The range test data consisted of RCS (dBsm) values for each of 360 one-deg azimuth angles around the attack helicopter. A symmetrical RCS table was created by using only half the data, corresponding to the right side of the aircraft, from nose (zero deg) to tail (180 deg). Symmetry is common among most aircraft designs; therefore, aircraft RCS data is usually entered for only one side and then mirrored in the opposite hemisphere. Figure 3.2-3 illustrates differences between the input data and its symmetrical conversion between 180 and 360 deg.

Table 3.2-4 lists selected statistical parameters used in comparing the raw inputs with symmetrical 1-degree RCS data, and shows the very small total variation attributable to imposing symmetry on the asymmetrical data set.

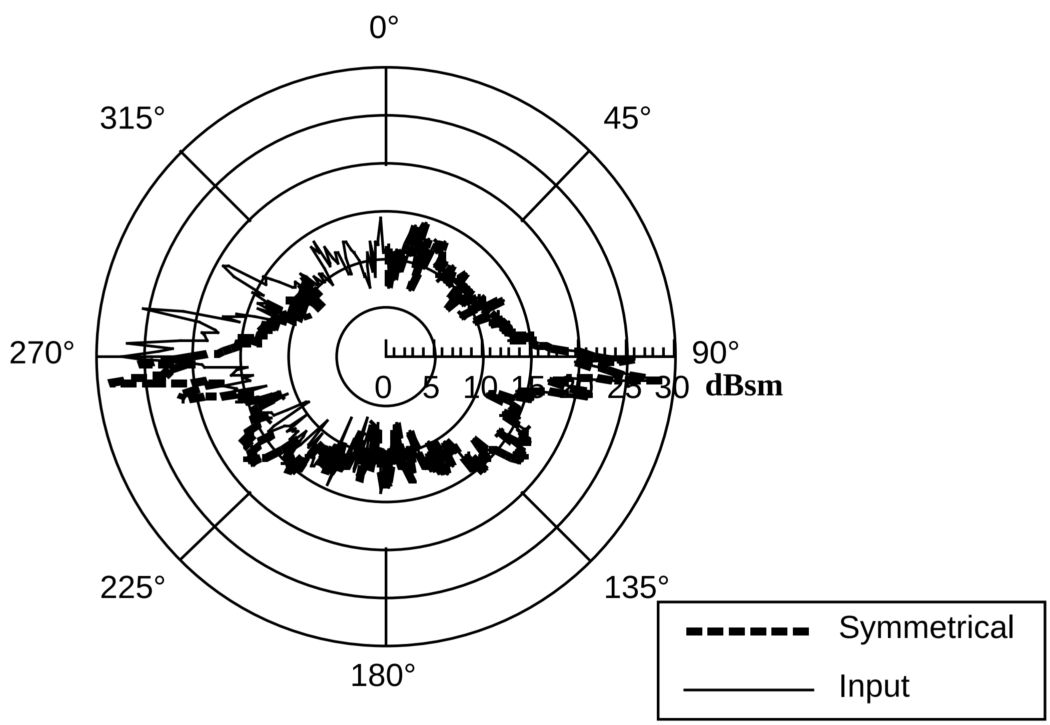


FIGURE 3.2-3. Symmetrical Conversion of RCS Data.

TABLE 3.2-4. Statistical Results of Raw Input vs. Symmetric Comparison.

Statistical Parameter	Symmetric Data	Raw Input Data
Mean	13.047	13.095
Median	12.096	12.303
Standard Deviation	3.524	3.549
Range	21.790	22.123

TABLE 3.2-4. Statistical Results of Raw Input vs. Symmetric Comparison. (Contd.)

Statistical Parameter	Symmetric Data	Raw Input Data
Minimum	7.020	6.687
Maximum	28.810	28.810
% Total Variation Between Groups	<<1%	
Correlation Coefficient	0.738	
Covariance Factor	9.201	

To convert the 1-deg RCS data to a 10-deg aspect-smoothed signature, a ten-point moving average was applied. Figure 3.2-4 depicts the aspect-smoothed result.

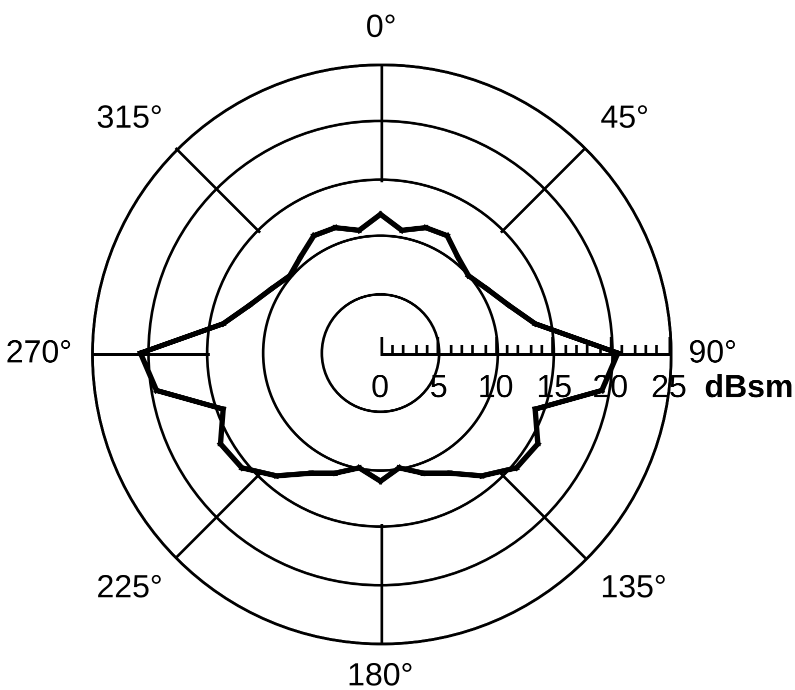


FIGURE 3.2-4. Smoothed 10-deg RCS Values.

The results of statistical comparisons between the 10-deg RCS model and the range test data are listed in Table 3.2-5. As expected, aspect smoothing caused a reduction in range variation and, therefore, range of the data set (22.1 to 10.5). The very small percentage of variation between groups and high covariance factor indicates little loss in fidelity. The correlation coefficient is relatively low, but this parameter is sensitive to sample interval differences, which in this case are an order of magnitude apart. Thus, a tenfold decrease in sample rate only yields a nominal correlation coefficient of 0.712.

TABLE 3.2-5. Statistical Results of Raw Input vs. Symmetric 10-deg Smoothed Comparison.

Statistical Parameter	Symmetric 10-Deg Smoothed Data	1-Deg Raw Input Data
Mean	13.144	13.095
Median	11.900	12.303
Standard Deviation	3.060	3.549
Range	10.500	22.123
Minimum	10.200	6.687
Maximum	20.700	28.810
% Total Variation Between Groups	<<1%	
Correlation Coefficient	0.712	
Covariance Factor	7.637	

<u>Validation Objective 2 – Symmetry, Smoothing, and Interpolation Effects</u>. This objective addressed a quantitative evaluation of the effects of both symmetry and aspect smoothing of the static signature on values produced by the model. Figure 3.2-5 depicts this comparison. Note that the range test data displays continuous and asymmetrical characteristics, while the interpolated outputs are discrete values produced at specific target aspect angles.

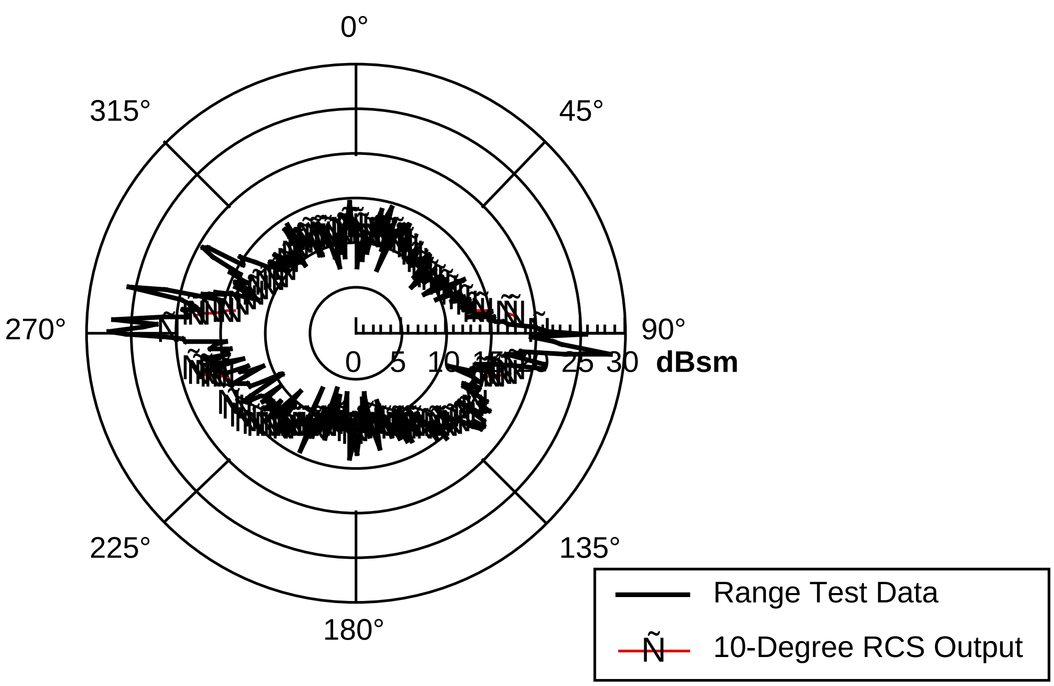


FIGURE 3.2-5. Comparison of Raw RCS Range Test Data with 10-deg Output Data.

The statistical parameters used in this comparison are listed in Table 3.2-6. Relatively minor losses in fidelity in this worst-case comparison were evident. Even the correlation coefficient, sensitive to sample interval, was no worse than nominal in value. The small variation in correlation coefficient (0.737) between this case and the symmetrical conversion (0.738) and aspect smoothing (0.712) cases suggests very little effect on data fidelity due to processing by the model.

TABLE 3.2-6. Comparison Between Range Test Data and Interpolated Output.

Statistical Parameter	*RADGUNS* Output RCS Data	Range Test RCS Data
Mean	13.169	13.096
Median	11.900	12.303
Standard Deviation	2.582	3.548
Range	10.500	22.123
Minimum	10.200	6.687
Maximum	20.700	28.810
% Total Variation Between Groups	<<1%	
Correlation Coefficient	0.737	
Covariance Factor	5.826	

Validation Objective 3 – Input-to-Output Comparison. This objective addressed processing of RCS data during simulation runs. Input values in the RCS tables were compared statistically with output values at time of detection when a specific S/N ratio was reached. Linear flight paths at 1000-m offsets were used to examine RCS values at detection range for one-half of each target's forward hemisphere. Several individual runs were made to verify that symmetry was correctly modeled in the opposite hemisphere. For each run, the detection point was identified by recording range, azimuth, and target RCS. For the aft hemisphere of each target, the RCS table was inverted, thus simulating flying the target through the test area backwards as shown in Figure 3.2-6.

The 1-degree RCS comparison is illustrated in Figure 3.2-7, where 1-degree inputs appear as a continuous line representing the 360-deg RCS coverage in the model. The outputs are depicted as discrete values that were produced by the model when the specified S/N ratio was reached.

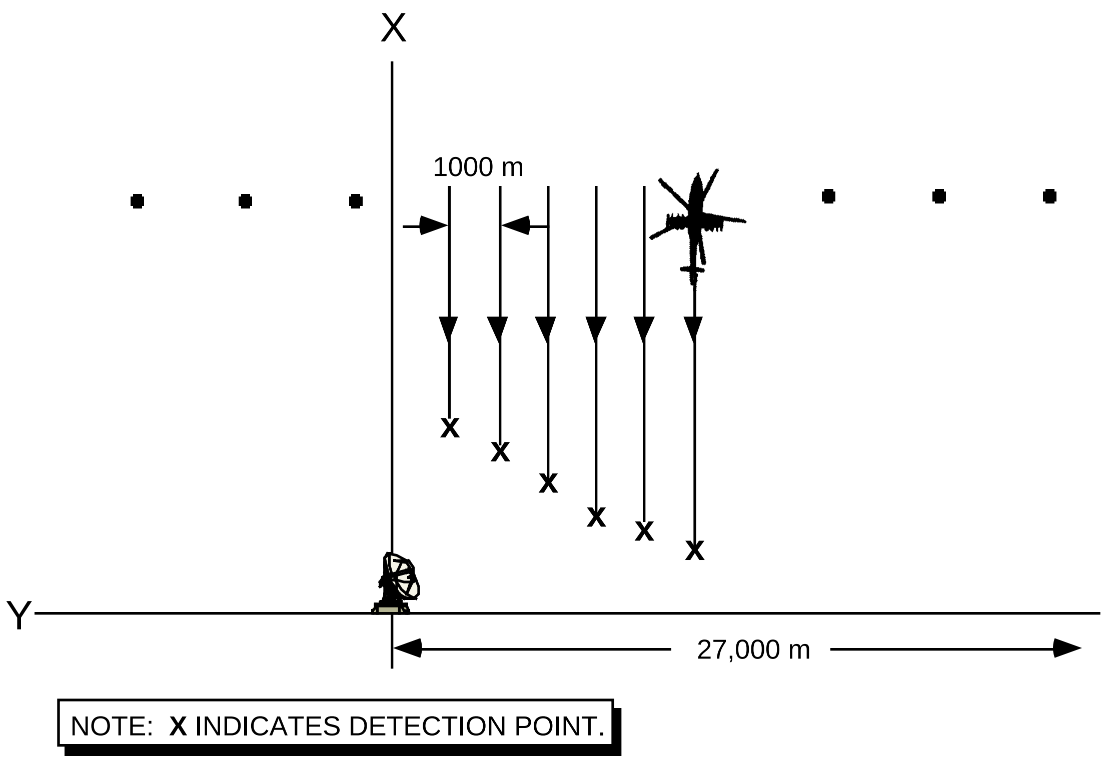


FIGURE 3.2-6. Linear Flight Path Geometry for Inverted RCS Table.

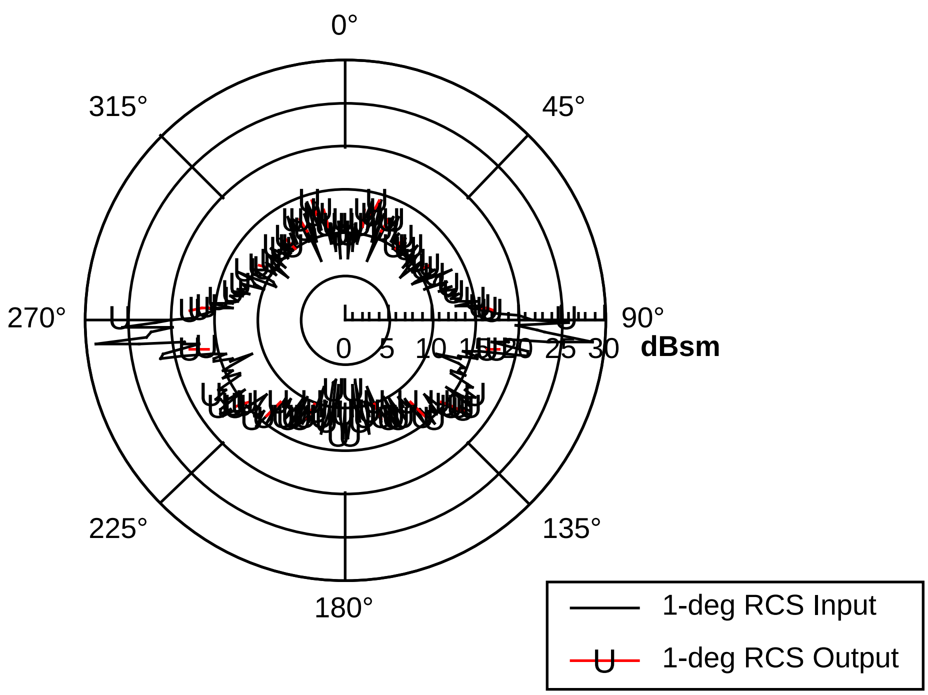


FIGURE 3.2-7. One-deg RCS Comparison.

Table 3.2-7 lists the statistical parameters applicable to this comparison of symmetrical input to interpolated output values. The relatively low correlation coefficient is again related to sampling interval differences. The remaining statistics are indicative of closely correlated and similar data sets.

TABLE 3.2-7. Statistical Results of 1-deg Input and Output Comparison.

Statistical Parameter	1-Deg Output RCS Data	1-Deg Input RCS Data
Mean	13.503	13.047
Median	12.800	12.096
Standard Deviation	3.019	3.524
Range	17.400	21.790
Minimum	8.500	7.020
Maximum	25.900	28.810
% Total Variation Between Groups	<1%	
Correlation Coefficient	0.832	
Covariance Factor	8.308	

The 10-deg aspect smoothed input and computed output comparison case is shown in Figure 3.2-8. Both the input and output data are plotted as discrete values due to the 10-deg resolution of inputs and the output values produced at specific target aspects.

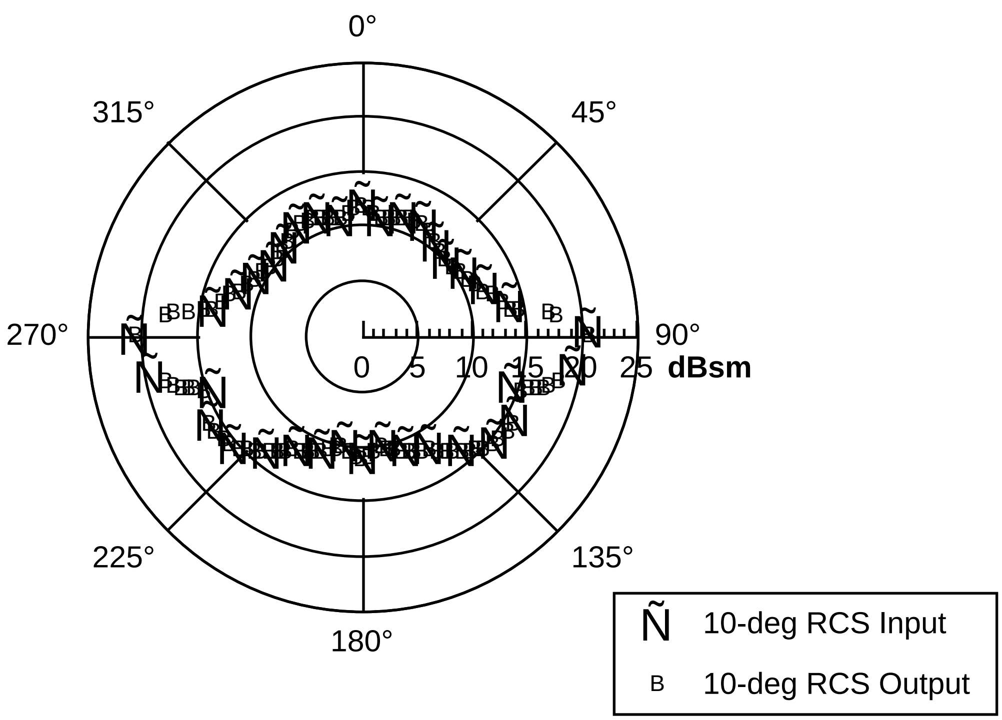


FIGURE 3.2-8. Ten-deg RCS Comparison.

The statistical comparison for the smoothed RCS input to output case is shown in Table 3.2-8, which again indicates accurate processing by the model. Note the extremely high correlation coefficient for this case. The dependence of this parameter on sampling interval is apparent here, where there is a one-to-one correspondence between data point counts. The other statistics listed reinforce the high correlation coefficient.

TABLE 3.2-8. Statistical Results of 10-Deg Input and Output Comparison.

Statistical Parameter	**10-Deg Output RCS Data**	**10-Deg Input RCS Data**
Mean	13.169	13.092
Median	11.900	11.750
Standard Deviation	2.582	3.097
Range	10.500	10.685
Minimum	10.200	10.015
Maximum	20.700	20.700
% Total Variation Between Groups	<<1%	
Correlation Coefficient	0.989	
Covariance Factor	1.769	

Validation Objective 4 – Target Signal Computation. For the purposes of this validation effort, there were two variables affecting target signal computation in *RADGUNS*: target range and RCS. *RADGUNS* computes target signal via the radar equation. In terms of the target echo power, S, the equation is:

$$S = \frac{P_r G_r^2 \lambda^2 \sigma}{(4\pi)^3 R^4 L_t}$$

where:

where:	P_r	=	Radar peak power output*
	G_r	=	Antenna gain*
	λ	=	Radar wavelength*
	σ	=	RCS
	R	=	Range
	L_t	=	Total loss factor*

The asterisked values above were default variables that were held constant. Echo power values computed from this equation were compared with those generated by the model at various ranges and target aspect angles. Both the dependence of target signal strength on range and RCS and the independence between RCS and range were examined through comparisons of output data and manual calculations.

A set of linear flight paths, as shown in Figure 3.2-9, was used. Along each 5000-m offset flight path, a number of measurements were made at each 5-deg azimuth increment (the intersections of flight paths with dotted radial lines emanating from the threat location at the origin). Each data point consisted of recording the azimuth, range, RCS, and target echo power.

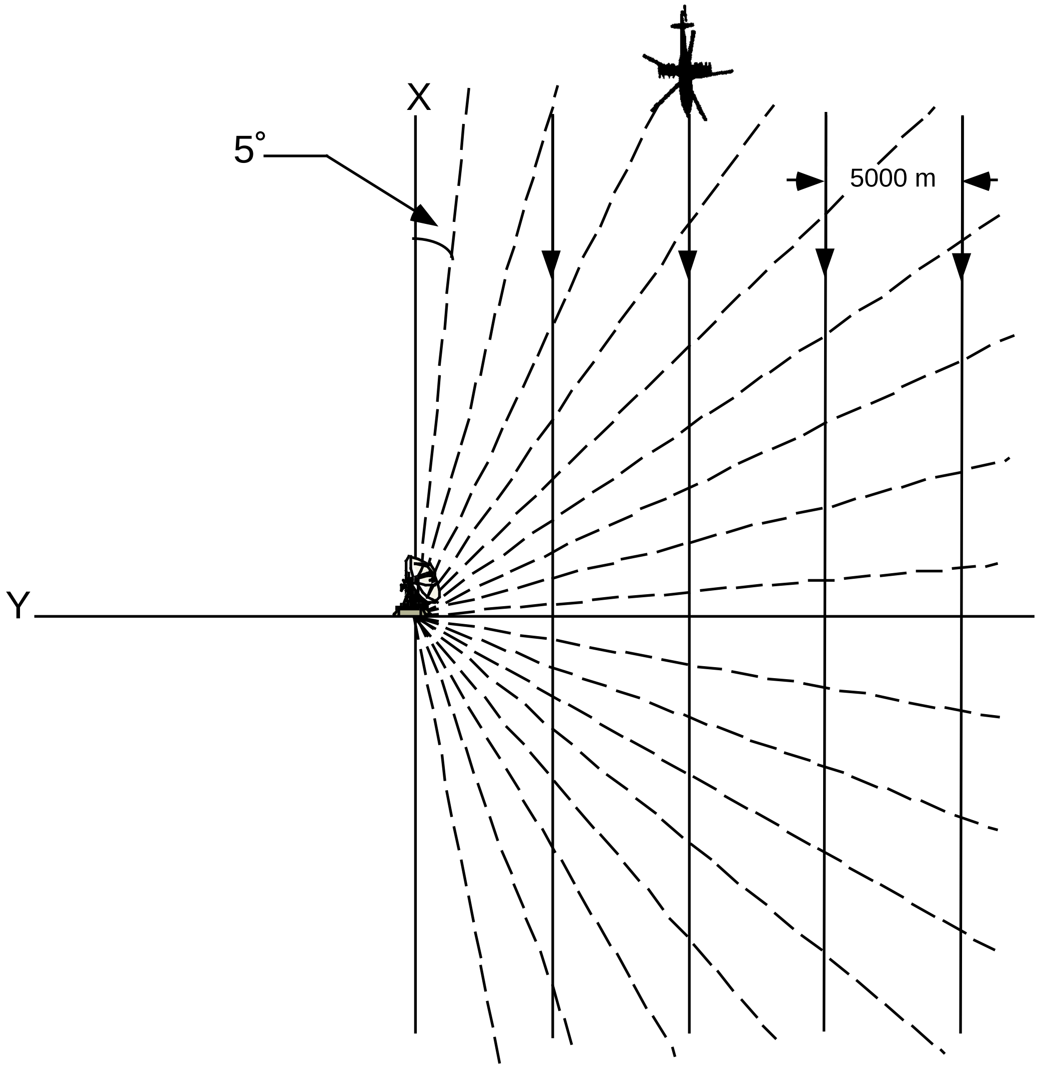


FIGURE 3.2-9. Illustration of Linear Target Signal Computation Flight Paths.

Linear flight paths were run for each RCS model (1-deg and 10-deg) to determine accuracy of RCS values computed at each target aspect angle. Values computed were correct for respective azimuth angles regardless of range from target. The 1-deg case is shown in Figure 3.2-10, where the runs are plotted against the 1-deg symmetrical input. Small variations in RCS values shown are due to angular resolution of the data output from the model.

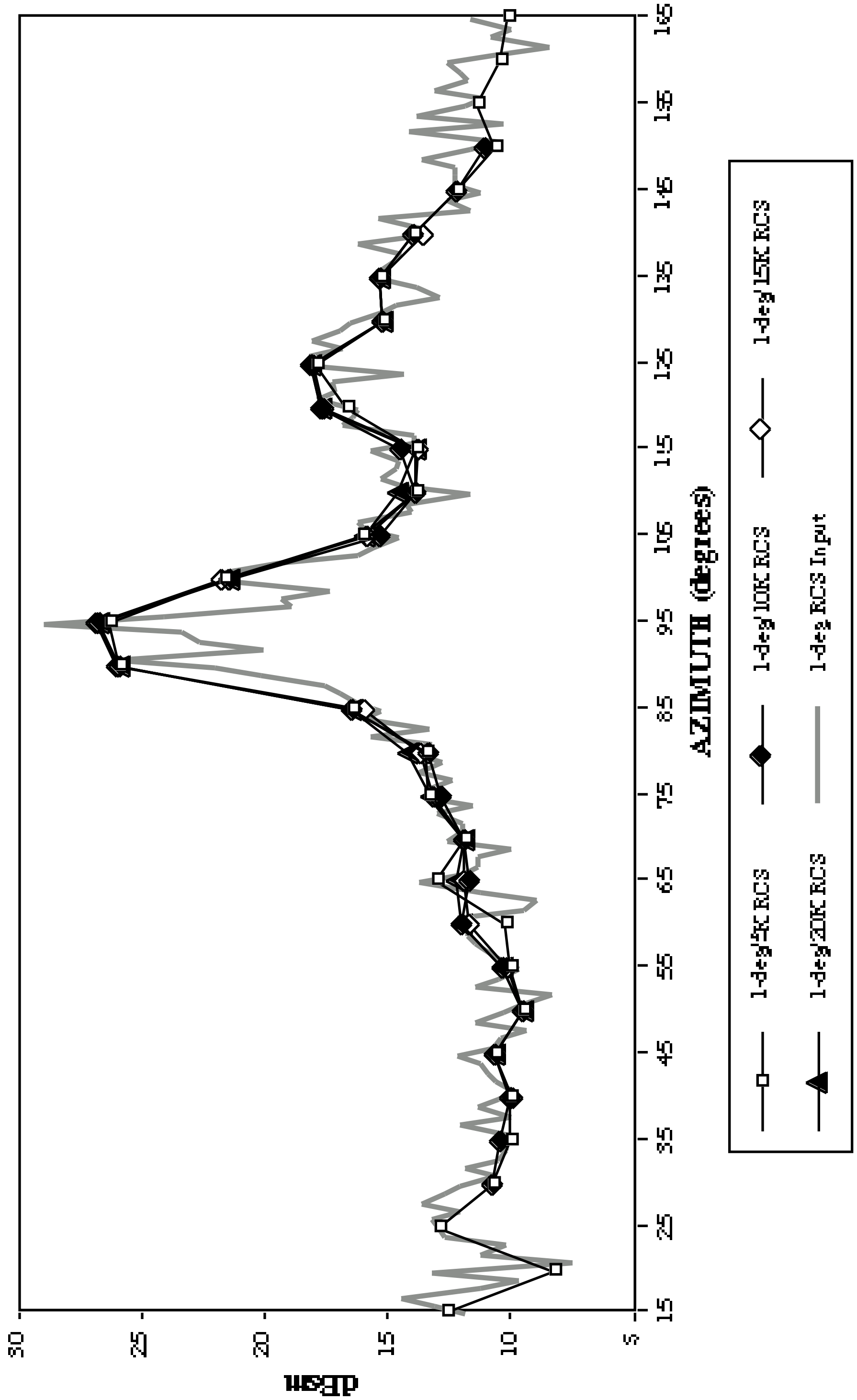


FIGURE 3.2-10. One-Degree RCS Azimuth Accuracy Comparison.

Tables 3.2-9, 3.2-10, and 3.2-11 contain the statistical data applicable to comparisons of the 1-degree input and output run set.

TABLE 3.2-9. Central Tendencies for 1-deg Relative Azimuth Assessment.

Statistical Parameter	1-Deg Input Baseline	1-Deg/5 K Offset RCS	1-Deg/10 K Offset RCS	1-Deg/15 K Offset RCS	1-Deg/20 K Offset RCS
Mean	13.806	13.597	14.344	14.952	15.432
Median	12.4	12.8	13.2	13.7	14.5
Standard Deviation	4.113	4.393	4.594	4.814	4.800
Range	19.3	18.0	17.2	17.3	17.2
Minimum	9.5	8.2	9.4	9.4	9.4
Maximum	28.8	26.2	26.6	26.7	26.6
% Total Variation Between Groups	2.2%				

TABLE 3.2-10. Correlation Coefficients for 1-deg Relative Azimuth Assessment.

	1-Deg Input Baseline	1-Deg/5 K Offset RCS	1-Deg/10 K Offset RCS	1-Deg/15 K Offset RCS	1-Deg/20 K Offset RCS
1-Deg Input Baseline	1				
1-Deg/5 K Offset RCS	0.952	1			
1-Deg/10 K Offset RCS	0.955	0.993	1		
1-Deg/15 K Offset RCS	0.953	0.994	0.998	1	
1-Deg/20 K Offset RCS	0.943	0.994	0.998	0.999	1

TABLE 3.2-11.

TABLE 3.2-11. Covariance Factors for 1-deg Relative Azimuth Assessment.

	1-Deg Input Baseline	1-Deg/5 K Offset RCS	1-Deg/10 K Offset RCS	1-Deg/15 K Offset RCS	1-Deg/20 K Offset RCS
1-Deg Input Baseline	16.368				
1-Deg/5 K Offset RCS	16.639	18.680			
1-Deg/10 K Offset RCS	18.539	20.144	20.262		
1-Deg/15 K Offset RCS	19.860	21.613	21.758	22.067	
1-Deg/20 K Offset RCS	19.923	21.866	22.002	22.264	21.830

The data presented in the previous three tables substantiate the graphical results shown in Figure 3.2-10 above. In particular, the correlation coefficients and covariance factors among the four offsets are extremely high, indicating a high degree of precision in the processing of 1-deg resolution RCS values within the simulation.

The next figure (Figure 3.2-11) illustrates run results for the 10-degree case, again plotted against the 1-degree RCS input baseline.

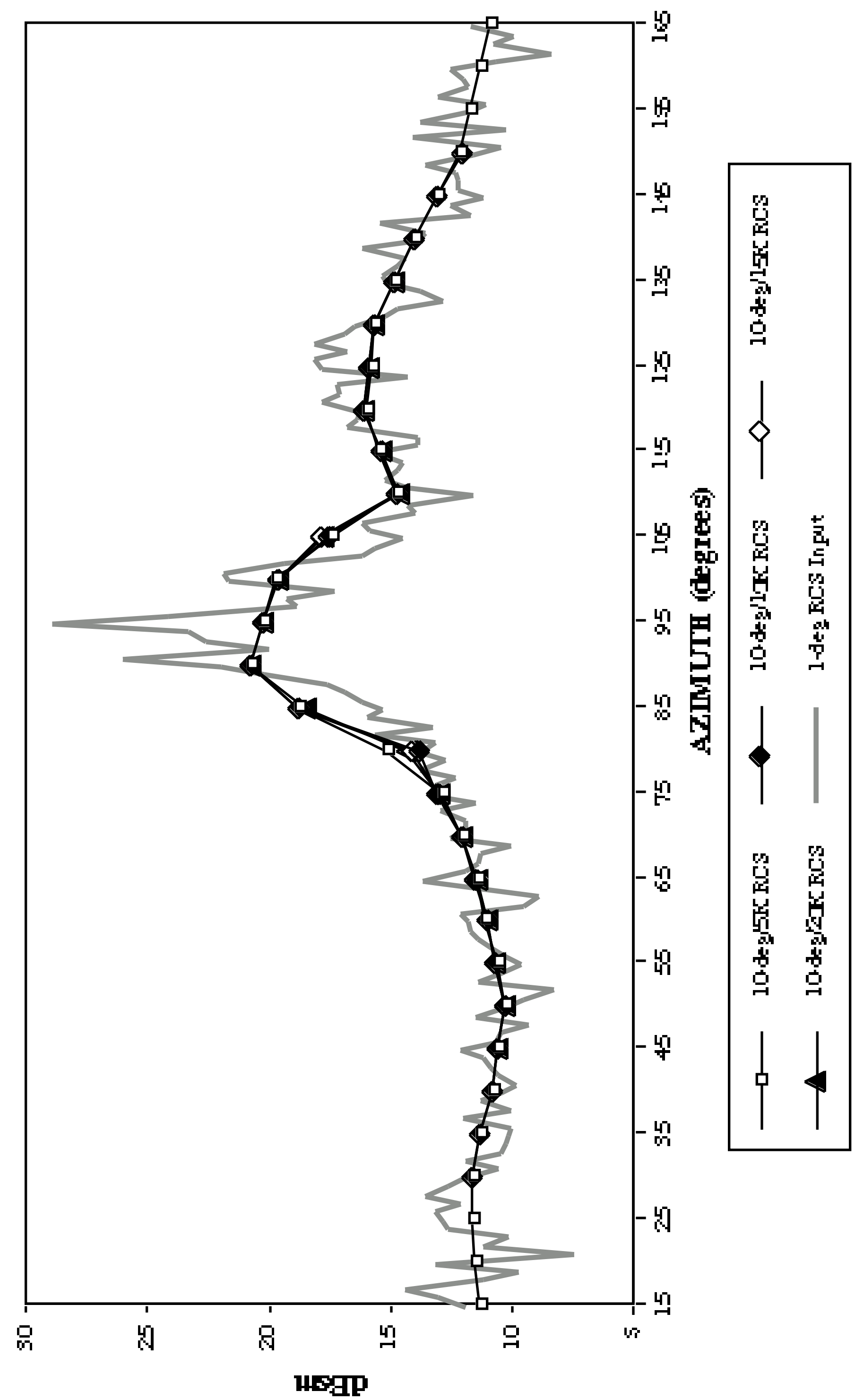


FIGURE 3.2-11. Ten-Degree RCS Azimuth Accuracy Comparison.

Tables 3.2-12, 3.2-13, and 3.2-14 summarize statistical parameters for the 10-deg run set comparisons.

TABLE 3.2-12. Central Tendencies for 10-deg Relative Azimuth Assessment.

Statistical Parameter	1-Deg Input Baseline	10-Deg/5 K Offset RCS	10-Deg/10 K Offset RCS	10-Deg/15 K Offset RCS	10-Deg/20 K Offset RCS
Mean	13.806	13.642	14.144	14.586	14.811
Median	12.4	12.1	13.7	14.7	14.8
Standard Deviation	4.113	3.113	3.219	3.372	3.388
Range	19.3	10.5	10.5	10.5	10.5
Minimum	9.5	10.2	10.2	10.2	10.2
Maximum	28.8	20.7	20.7	20.7	20.7
% Total Variation Between Groups	1.6%				

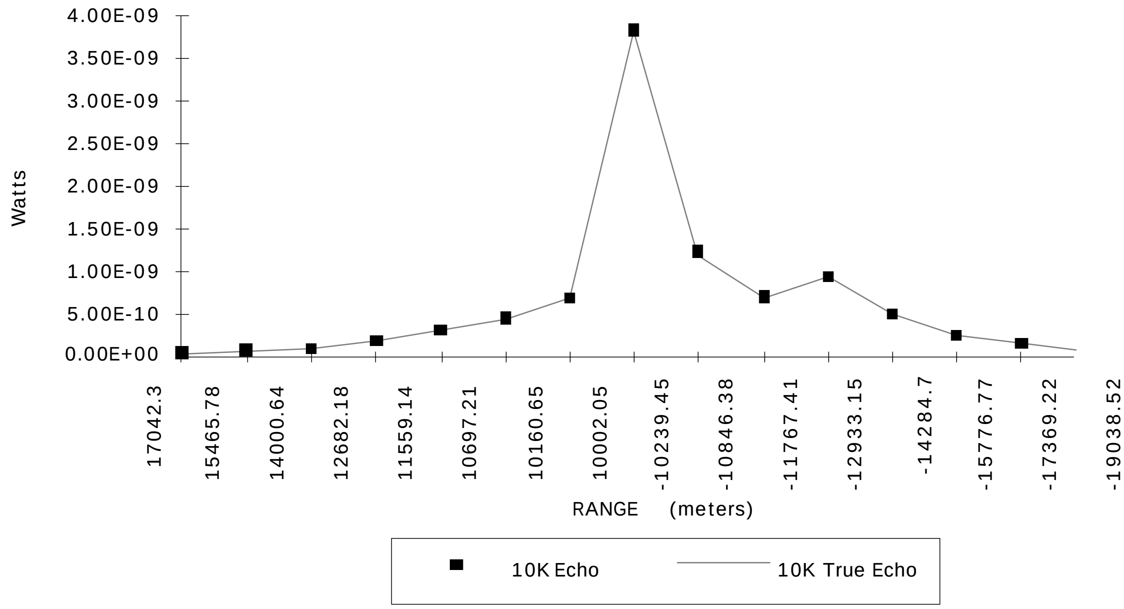
TABLE 3.2-13. Correlation Coefficients for 10-deg Relative Azimuth Assessment.

	1-Deg Input Baseline	10-Deg/5 K Offset RCS	10-Deg/10 K Offset RCS	10-Deg/15 K Offset RCS	10-Deg/20 K Offset RCS
1-Deg Input Baseline	1				
10-Deg/5 K Offset RCS	0.860	1			
10-Deg/10 K Offset RCS	0.860	0.996	1		
10-Deg/15 K Offset RCS	0.843	0.997	0.999	1	
10-Deg/20 K Offset RCS	0.838	0.998	0.999	0.999	1

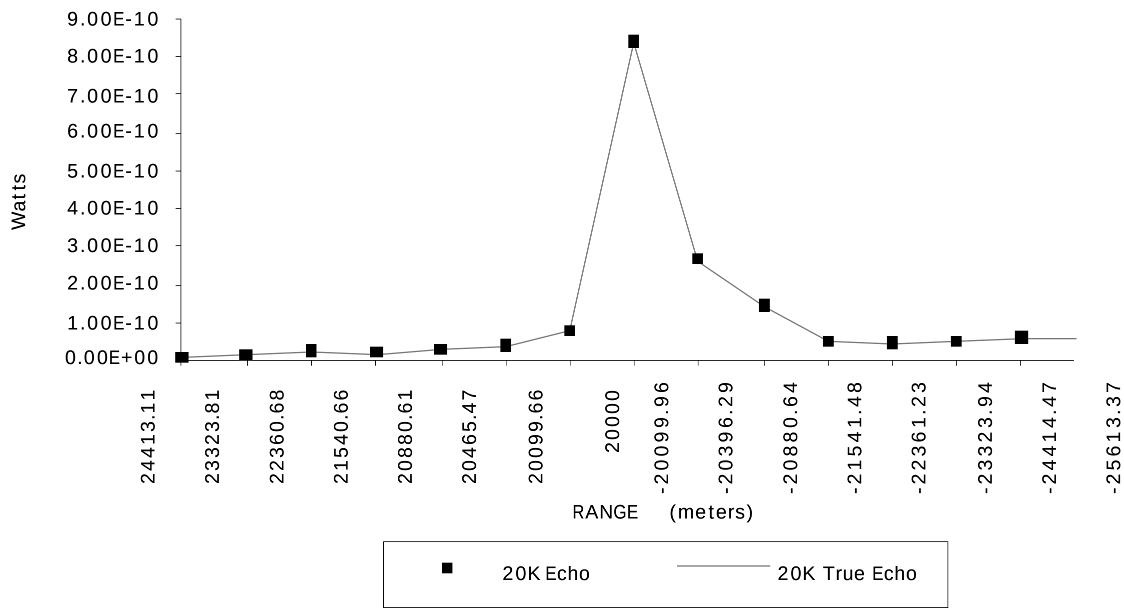
TABLE 3.2-14. Covariance Factors for 10-deg Relative Azimuth Assessment.

	1-Deg Input Baseline	10-Deg/5 K Offset RCS	10-Deg/10 K Offset RCS	10-Deg/15 K Offset RCS	10-Deg/20 K Offset RCS
1-Deg Input Baseline	16.368				
10-Deg/5 K Offset RCS	10.656	9.380			
10-Deg/10 K Offset RCS	11.693	9.956	9.949		
10-Deg/15 K Offset RCS	12.307	10.759	10.742	10.827	
10-Deg/20 K Offset RCS	12.499	10.912	10.885	10.975	10.871

Results indicate that the simulation also processes 10-deg resolution RCS data by interpolation of the correct relative azimuth for the flight path geometry. In the 10-deg case, independence between range and RCS is apparent. As expected, the percentage of total variation between groups is lower for the smoothed 10-deg than for the 1-deg data. Correlation coefficients and covariance factors for 10-deg resolution data are slightly lower than those of the 1-deg resolution baseline.



(a) One-Degree/10K Offset Target Echo.



(b) One-Degree/20K Offset Target Echo.

FIGURE 3.2-12. One-deg Target Echo Comparison.

To validate target echo computational accuracy, four simulation runs were made at offsets of 10,000 and 20,000 m each for both the 1-deg and 10-deg RCS models. In each of the run results, model output echo power was both measured and calculated using RCS and range via the radar range equation. Calculated target echo power values (shown as “true”) were compared with model outputs for accuracy. Figure 3.2-12 illustrates the cases for the 1-deg input signature data.

Table 3.2-15 summarizes the pertinent statistical parameters derived from variance analysis of the two 1-deg runs. These values indicate accurate calculation of target return (echo) as a function of target aspect, range, and RCS.

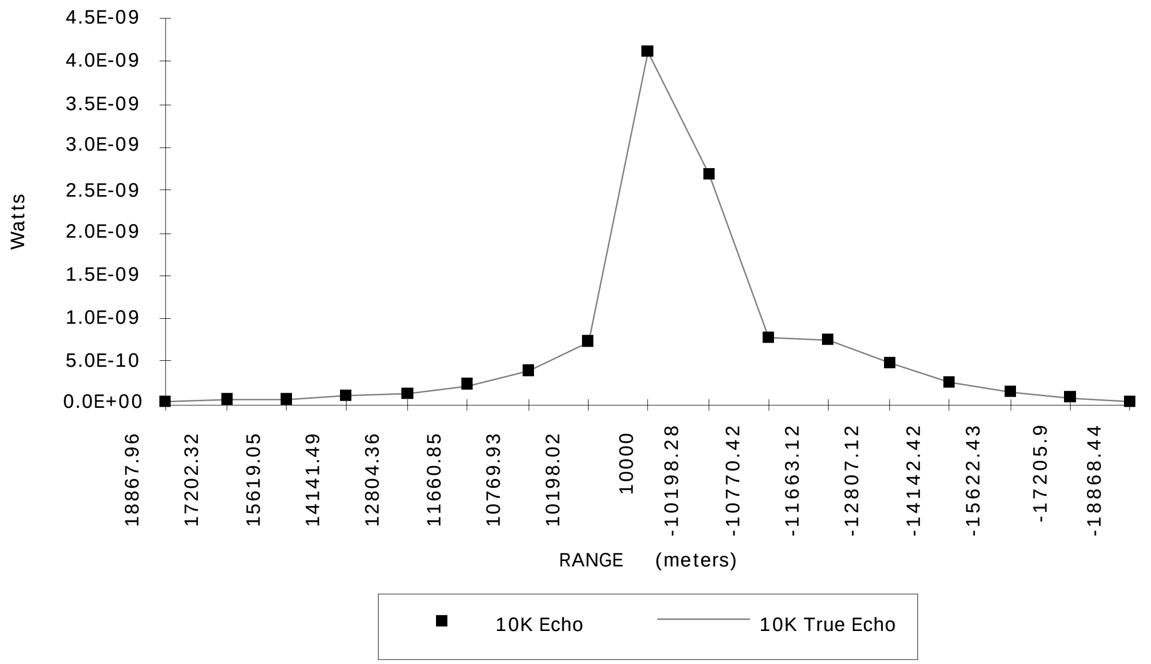
TABLE 3.2-15. One-deg Target Echo Run Comparisons.

Statistical Parameter	1-Deg/10K Echo	1-Deg/10K True	1-Deg/20K Echo	1-Deg/20K True
Mean	5.960E-10	5.961E-10	1.109E-10	1.110E-10
Median	2.830E-10	2.830E-10	4.965E-11	4.961E-11
Standard Deviation	9.305E-10	9.316E-10	2.045E-10	2.046E-10
Range	3.789E-09	3.791E-09	8.308E-10	8.313E-10
Minimum	4.120E-11	4.437E-11	1.020E-11	1.023E-11
Maximum	3.830E-09	3.836E-09	8.410E-10	8.415E-10
% Total Variation Between Groups	<<1%		<<1%	
Correlation Coefficient	0.999		0.999	

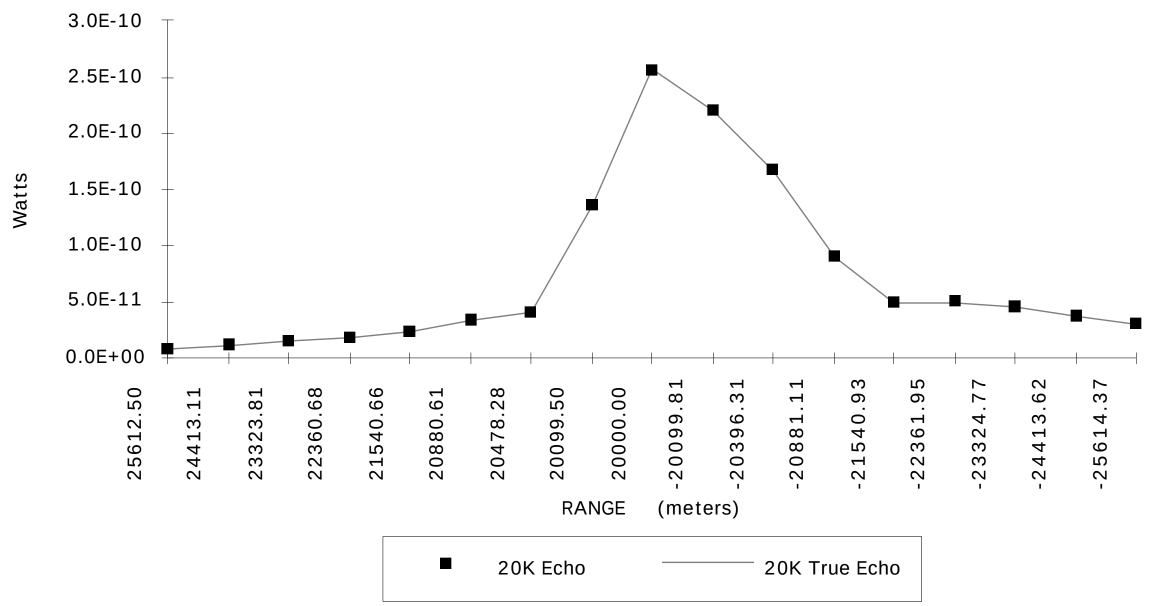
Figure 3.2-13 depicts the 10-deg cases and Table 3.2-16 lists the statistical parameters associated with the 10-deg runs. Again, statistics indicate correct calculation of target echo as a function of aspect angle, range, and RCS. The results in both the 1-deg and 10-deg cases show extremely high correlation coefficients, indicating correct computations by the radar equation implemented in *RADGUNS*.

TABLE 3.2-16. Ten-deg Target Echo Run Comparisons.

Statistical Parameter	10K RADGUNS	10K Calculated	20K RADGUNS	20K Calculated
Mean	6.539E-10	6.537E-10	7.548E-11	7.561E-11
Median	2.310E-10	2.303E-10	4.365E-11	4.399E-11
Standard Deviation	1.096E-09	1.096E-09	7.793E-11	7.809E-11
Range	4.082E-09	4.084E-09	2.483E-10	2.489E-10
Minimum	3.850E-11	3.857E-11	8.750E-12	8.758E-12
Maximum	4.120E-09	4.123E-09	2.570E-10	2.577E-10
% Total Variation Between Groups	<<1%		<<1%	
Correlation Coefficient	0.999		0.999	



(a) Ten-Degree/10K Offset Target Echo.



(b) Ten-Degree/20K Offset Target Echo.

FIGURE 3.2-13. Ten-deg Target Echo Comparison.

Conclusions

RADGUNS performs the RCS calculation precisely and accurately. The model is capable of processing any reasonable level of resolution of RCS data but is currently limited to 181 samples per roll/pitch angle. The data entered into an RCS table is faithfully recalled and interpolated for a particular target attitude. RCS data fidelity losses due to symmetry conversion, aspect smoothing, and simulation processing, both separately and combined, were insignificant. While high-fidelity RCS signatures (1-deg resolution) may be a requirement for some simulations, 10-deg aspect-smoothed, symmetric RCS data is adequate for most scenarios addressed by *RADGUNS*. The radar range equation used to determine target echo power as a function of RCS and range provides values nearly identical to manual calculations. The implementation of the target model in RADGUNS is somewhat flexible as to input format, correctly interpolates values between those in the input table, and provides a reasonable approximation of the dynamics of radar signals echoed from a far-field target (static) at a particular aspect angle (attitude).